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1. Your reference
535GB

2. Patent application number
(The P
0200925.6

16 JAN 2002

3. Full name, address and postcode of each applicant *(underline all surnames)*

Renishaw plc
New Mills
Wotton-under-Edge
Gloucestershire, GL12 8JR

Patents ADP number *(if you know it)*

2691002

If the applicant is a corporate body, give the country/state of its incorporation

United Kingdom

4. Title of the invention

Aligning Optical Components of an Optical Measuring System

5. Name of your agent *(if you have one)*

E C Leland et al

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Renishaw plc, Patents Department
New Mills
Wotton-under-Edge
Gloucestershire
GL12 8JR

Patents ADP number *(if you know it)*

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Number of earlier application	Date of filing *(day / month / year)*

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a) any applicant named in part 3 is not an inventor, or
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I/We request the grant of a patent on the basis of this application.

Signature [signature] Date 16.01.02

AGENT FOR THE APPLICANT

Name and daytime telephone number of person to contact in the United Kingdom A ILES 01453 524524

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ALIGNING OPTICAL COMPONENTS OF AN OPTICAL MEASURING SYSTEM.

The present invention relates to a method of and apparatus for aligning the components of an optical measuring system preparatory to using them in a measuring operation.

One known type of optical measuring system consists of two or more housings, at least one of which is to be fixed to the bed of the machine and another one of which is to be carried by the movable arm or spindle of the machine. One of the housings contains one or more light sources and detectors, and will be referred to hereinafter as the "source housing" while the other housing contains reflectors, and will be referred to hereinafter as the "reflector housing". Usually the source housing is maintained in a fixed position on the bed of the machine and the reflector housing is mounted on a part of the machine moveable with respect to the machine bed e.g. the machine spindle.

Aligning the optical components is often a time-consuming process which involves firstly the alignment of the source housing so that the beam or beams generated are directed along, or parallel to, one or more of the X,Y and Z axes of the machine. Then the reflectors have to be aligned with the beam or beams so that the reflected beams are directed back onto the detectors. Depending on the type of detectors being used the alignment may have to be accurate to within a few arc seconds.

A first aspect of the invention provides a connector device comprising:

a stem with a first end and a second end, such that the first end may be inserted into a first receiving meahs and the second end may be inserted into a second receiving means;

wherein said stem is divided into two halves along its longitudinal axis, with a bridging portion joining the two halves;

and an actuator which locks both the first and second ends of the stem within the first and second respective receiving means.

Preferably the actuator comprises a locking device in one of said first and second receiving means which pushes the two halves of one end of the stem together which results in the opposite end of the stem having the two halves pushed apart and against the respective receiving means.

Preferably the stem is provided with a protrusion at each end.

A second aspect of the invention provides an optical measuring system for a machine comprising:

a first housing attached to a first surface of the machine;

a second housing attached to a second surface of the machine, said second surface of the machine being moveable with respect to said first surface of the machine;

said first and second housings each being provided with a complementary part of a first mounting device,

such that when the two parts of the first mounting device are connected together, the housings are mutually aligned and aligned with a known direction of the relative movement of the moving part of the machine;

wherein said fixed surface of the machine and a plurality of surfaces of the first housing are each provided with a complementary part of a second mounting device, such that when the two parts of the second mounting device are connected together, the first and second housings may be aligned in one of the X,Y,Z,-X and -Y axes of the machine.

Once the first and second housings have been aligned using the first mounting device, the orientation of the second mounting device between the first housing and the fixed surface of the machine is arranged such that realignment of the first and second housings relative to one another is not required.

The second housing may be connected to the moving surface of the machine by a connecting device. A plurality of surfaces on the second housing and a plurality of surfaces of the connecting device are each provided with a complementary part of a third mounting device, such that when the two parts of the third mounting device are connected together, the connecting device is correctly aligned for connection to the moving part of the machine.

Once the first and second housings have been aligned using the first mounting device, the orientation of the third mounting device between the second housing and the connecting device is arranged such that realignment

of the first and second housing relative to one another is not required.

Preferably the geometric combination of the first and housings is such that the moving part of the machine starts in the same position in x,y,z when connecting to the second housing, whatever is the orientation of the first and second housings.

A third aspect of the invention provides an optical measuring system for a machine comprising:

a housing attached to a fixed surface of the machine

wherein said fixed surface of the machine and a plurality of surfaces of the housing are each provided with a complementary part of a mounting device, such that when the two parts of the mounting device are connected together, the housing may be aligned in one of a plurality of known directions;

wherein a cable leads to the housing and wherein the cable is provided with a cable mounting device;

and wherein the cable mounting device may be positioned on the fixed surface such that at each orientation of the first housing, the cable transmits an equal force on the housing.

A fourth aspect of the invention apparatus for the controlled lowering of a housing of an optical measuring system onto a surface of a machine comprising a platform onto which the housing may be mounted such that rotation of the platform in a first direction causes the platform to be raised and rotation of the platform in a second opposite direction causes the platform to be lowered;

wherein the housing may be placed on the raised platform and the platform rotated to lower the housing towards the surface.

A fifth aspect of the invention provides apparatus for adjusting the angle of a base about an axis of an optical measuring system mounted on a surface of a machine comprising:

an inclined surface on the surface of the machine;

a moveable member mounted on the inclined surface, on which in turn the base is mounted;

a pivot between the base and the surface of the machine;

such that when the moveable member is moved in a first direction along the inclined surface, it moved upwards and causes the base to pivot about the pivot point in one direction and when the moveable member is moved in a second opposite direction along the inclined surface, it moves downwards and causes the base to pivot about the pivot point in an opposite direction.

Preferably the inclined surface comprises a pair of rollers and the moveable member comprises a ball.

Preferably apparatus is provided to pivot the base about each of the X,Y and Z axes.

The invention will now be described, by way of example only, and with reference to the following drawings in which:

Fig 1 is a diagrammatic elevation of the component of a prior art optical measuring system;

Fig 2 is a side view of an adjustable connector according to the invention;

Figs 3A-3B are views of the source and reflector housings aligned along the X,Y,-X,-Y and Z axis directions;

Figs 4A and 4B show the geometric combination of the source and reflector housings aligned along the Y and Z directions;

Fig 5A is a plan view of the optical measuring system aligned with the Z axis;

Fig 5B is a side view of the optical measuring system aligned with the Z axis;

Fig 5C is a plan view of the optical measuring system aligned with the X-axis;

Fig 5C is a side view of the optical measuring system aligned with the X axis;

Figs 6A-D show plan and side views of the controlled lowering platform;

Fig 7A and 7B show side and end views respectively of the base plate adjusting device; and

Fig 8 illustrate a ball-bar embodiment of the invention.

Referring to the drawings, Fig 1 shows a prior art embodiment of an optical measuring system for mounting on a machine as disclosed in co-pending application PCT/GB01/03096 filed on 11th July 2001.

The optical measuring system includes a base plate 10, a source housing 20 and a reflector housing 22, all of which need to be properly aligned with one or more of the machine axes. The base plate 10 is connected to the bed of the machine by screws 12, 14.

The source housing 20 may contain an autocollimator formed in optical sequence by, a light source 24, a

beam splitter 26, a collimating lens 28 through which a collimated light beam passes out of the housing, and a detector 30 which receives a return light beam from the reflector 32 in thereflector housing 22 via the beam splitter 26.

The source housing 20also includes a kinematic seat in the form of three spherical seating elements 16 arranged in a triangular array and spaced at 120° apart. The seating elements 16 co-operate with three V - shaped grooves (not shown) on the base plate to form a conventional kinematic seat for repeatable positioning of the housing on the base plate.

The source housing has a further kinematic seat 18 on its front face (ie the face which is orthogonal to the beam direction) on which the reflector housing may be seated. The light source and the reflector are aligned during the manufacturing stage to ensure that when the reflector housing is seated in the kinematic seat 18 on the front fact of the housing, the light beam and reflector are properly aligned.

It can be seen therefore that once the source housing 20 is correctly aligned to direct a light beam along one of the machine axes, eg the X-axis, the reflector housing 22 can be seated on the kinematic seat 18 on the front face of the source housing 20, and will automatically be aligned with the beam from the light source 24. Magnets 33 are used to urge the two housings 20,22 together at the kinematic seat 18.

In order to take care of any mis-match in position between the machine spindle 34 and the reflector

housing 22 when the two are to be connected together, the reflector housing 22 is provided with a limited amount of compliance by using an adjustable connector by means of which the housing 22 can be connected to the spindle 34 of the machine. The adjustable connector has a ball 36 which is to be seated in a socket 38 on the machine spindle. The ball 36 is adjustably supported in a retaining device 40 which, in turn is connected to the reflector housing 22, by any suitable means.

A preferred embodiment of the adjustable connector will now be described with reference to fig 2. The socket 38 of the machine spindle comprises a cylindrical bore which houses ball 36 of the adjustable connector. The retaining device 40 also comprises a cylindrical bore 42 and is mounted on the reflector housing 22, preferably by kinematic mounts 52.

The ball 36 of the adjustable connector is connected by a stem 46 to a further ball 48 which lies inside the bore 42 of the retaining device 40.

The Balls 36 and 48 of the adjustable connector may only have a part spherical surface at the portion of the ball in contact with the surface of the cylindrical bore.

The ball 36 can be adjusted through a limited angle to enable it to be engaged in the socket 38 of the machine spindle. The ball is retained in socket 38 in known manner by providing magnets (not shown) in the ball 36, the socket 38, or both.

Two slits 54,56 extends from opposite ends of the adjustable connector along its longitudinal axis to just short of its centre, leaving just a small bridging portion 57 connecting the two halves of the adjustable connector together. A locking screw 58 is provided in the socket 38 of the machine spindle which when tightened pushes against the ball 36, thus fixing the ball 36 within the socket 38 and also pushing the two halves of the ball 36 together. The bridging portion 57 of the adjustable connector acts as a hinge and as the two halves of ball 36 are pushed together, the two halves of ball 48 are pushed apart and against the sides of the cylindrical bore 42, fixing it in position.

This connector thus has the advantage that one actuation locks both balls.

Once the source housing 20 has been aligned with an axis of the machine, the reflector housing 22 attached to the machine spindle can be brought up to the source housing 20. With the locking screw loosened, the adjustable connector will be free enough to rotate so that the reflector housing 22 will seat in the kinematic seat 18. By this means automatic alignment of the source housing 20 and the reflector housing 22 can be ensured. Once seated in the kinematic seat 18 the locking screw is tightened to maintain the orientation of the housing 22.

It is desirable to align the source housing 20 with other machine axes. In the above described example, where the source housing is mounted on a base plate, the source housing may have other sets of kinematic

elements on its lower surface or on other ones of its orthogonal faces. By this means it can be rotated through 90 ° in different planes and be re-seated on the kinematic seat on the base plate in different orientations with the light beam from the source directed along different ones of the machine axes. The reflector housing will continue to seat in the same kinematic seat 18 on the source housing so that it will also be aligned with the different axes.

Figs 3A-D shows the plan view of the source housing 20 and reflector housing 22 on the base plate 10. Fig 3a shows the light beam aligned with the X axis, Fig 3b shows the light beam aligned with the Y axis, Fig 3c shows the light beam aligned with the -X axis and Fig 3d shows the light beam aligned with the -Y axis. Fig 3e shows a side view with the light beam aligned with the Z axis.

A set of kinematics elements are provided on the base plate and source housing to define each of the X, Y, Z, -X, -Y directions. Each set of kinematics are not necessarily independent, with balls or V-shaped grooves from one set also forming part of another set.

Once the source and reflector housings 20,22 have been aligned for the first axis sing the kinematic seat 18, the orientations of the kinematic elements between the source housing 20 and the base plate 10 and between the reflector housing 22 and the retaining device 40 means that for subsequent axes, realignment of the source and reflector housings 20,22 on the kinematic seat 18 is not required.

For each position of the source and reflector housing 20,22, the retaining device 40 which holds the adjustable connector must be mounted on the reflector housing 22 in a different position. The location of the retaining device 40 in each respective position of the retaining device on the reflector housing is defined by a respective kinematic seat. A different set of kinematic elements is thus provided between the reflector housing 22 and the retaining device 40 for each position of the retaining device. As before, each set of kinematics may share elements with another set.

For calibration of large machines, it is desirable to start with the source housing 20 in the middle of the machine and first move the reflector housing 22 along one axis (eg X axis) and then turn the source and reflector housings 20, 22 around 180° and move the reflector housing along that axis in the opposite direction (eg -X axis). It is thus desirable for the source housing 20 and base plate 10 to have kinematics defining the -X and -Y directions.

There are thus five sets of kinematics defining the X,Y,Z,-X and -Y directions, although each set is not necessarily independent from the other sets.

As illustrated in figs 4A and 4B, the geometric combination of the source housing 20 and the reflector housing 22 allow the same co-ordinate start position for calibration of x,y and z axis after initial set up.

Fig 4A shows the source housing 20 being aligned along the Y axis and fig 4B shows the source housing 20 aligned along the Z axis. In both cases the distance a

between the quill 34 and the reflector housing 22 is the same. Thus when calibrating in different orientations (ie along the X,Y or Z axes), the start point is always the same.

The optical source may be located remotely from the source housing, particularly as heat from the optical source may cause distortion on the housing. An optical fibre may thus be used to channel the light from the light source to the source housing.

The source housing is provided with a supply cable which houses the optical fibres. This is shown in figs 5A-D. Figs 5S and 5B show the plan and side view respectively of the source housing 20 aligned with the Z axis. Figs 5C and 5D show the plan and side view respectively of the source housing aligned with the X axis. The supply cable 60 transmits forces due to its bending onto the source housing 20 which may result in the source housing not sitting squarely on the kinematic seat 16. It is therefore desirable to minimise the force due to the bending of the cable 60.

The supply cable 60 is provided with a cable mounting block 62 which may be attached to the base plate 10. The mounting block can be clipped into various locations on the base plate 10 depending upon the orientation of the source housing 20. The position of the cable mounting block 62 on the base plate is defined by a kinematic seat and is held in position by magnets (not shown).

The cable mounting block 62 has a plurality of angled faces, such that in different orientations of the

source housing 20, different faces of the cable mounting block may be clipped onto the base plate 10, by way of a respective kinematic seat on that face.

The position of the kinematic seats and the angles of the faces of the cable mounting block 62 ensures that minimal and equal forces from the cable are transmitted to the source housing for each orientation of the source housing.

Repeated lowering of the source housing onto the base plate could result in damage to the kinematic surfaces. In the present embodiment the base plate is provided with a controlled lowering platform so that the source block is lowered onto the kinematics in a repeatable way which minimizes the risk of impact damage.

Fig 6A shows a first embodiment of the controlled lowering platform. A lifting platform 64 is provided onto which the source housing 20 may be placed. This is seperated from the base plate by a rotatable disc 66. Ball bearings 68 are located between the disc 66 and the base plate 10 and between the disc 66 and the lifting platform 64 to allow rotation of the disc 66. The surface of the disc 66 is provided with tapered grooves into which the ball bearings 68 are seated. When the ball bearings are seated in the wide portion of the groove, the lifting platform 64 is in its lowered position. However as the disc 66 is rotated, the groove presents its narrower portion to the ball bearing 68 resulting in the lifting platform 64 being raised. By moving the disc 66 in the opposite direction, the lifting platform 64 may gently be lowered.

A damper 70 is provided to smooth the movement of the lifting platform 64. The damper 70 may be provided on a lever 72 which is used to rotate the disc 66. Alternatively the damper 70 may be located between the base plate 10 and the lifting platform 64, as shown in fig 6B.

A second embodiment of the controlled lowering platform is illustrated in figs 6C and 6D. In this embodiment, the lifting platform 64 is provided with a downwardly dependent cylinder 74 with a threaded outer surface. The central disc is replaced by a ring 76 with a threaded inner surface. Rotation of the ring 76, using the lever 72 will result in the lifting platform 64 being raised by rotation in one direction and the lifting platform being lowered in the opposite direction.

As in the previous embodiment, a damper 70 may be provided on the lever 72 as shown in fig 6C or between the base plate 10 and the lifting platform 64, as shown in fig 6D.

The base plate 10 must be aligned in the X-Y plane and this is normally achieved by mounting it on an accurately horizontal machine bed. However if the machine bed is not accurately horizontal, then adjustments on the base plate is required.

Figs 7A and 7B illustrate an adjustment mechanism on base plate 10. A pair of rollers 83,84 are provided on which a ball bearing 86 is seated. The rollers 83,84 are angled from the X-Y plane so that movement of the

ball 86 in the direction of arrow A causes the ball to move upwards and movement of the ball in a direction opposite to arrow A causes the ball to move downwards. Base plate 10 has a pad 88 on its lower surface which is mounted over the ball bearing 86.

A second ball bearing 90 is provided between the base plate 10 and machine bed 80 and acts as a pivot. Therefore by turning the adjustment screw 92 the ball 86 may be moved along the rollers, thus pivoting the base plate 10 about the ball bearing 90.

Three such adjustment devices may be provided on the base plate, all using the same pivot point, to allow the base plate to be adjusted about the X,Y and Z axes.

In yet another embodiment as shown in Fig 8, the two housings 20 and 22 form two parts of a ball-bar. A first part has a ball 100 capable of seating in a cup 102 magnetically retained in the machine bed by magnets 101. A housing 104 is connected to the ball and contains the light source and interferometer optics of a linear measurement interferometer 105. The second part has a ball 106 capable of seating in a cup 108 magnetically retained by the machine spindle by magnets 107; and has a housing 110 which contains the retroreflector 109 of the interferometer. Preferably the cups each contain three pads on which the balls 100 and 106 are kinematically seated. The two parts of the ball-bar are joined at a kinematic joint 114 formed by seating elements on each part of the ball-bar which are urged into engagement by magnets 116.

In order to align the ball-bar along a machine axis for

taking measurements, the cup 102 is positioned on the machine and ball 100 of the first part is brought down to seat on cup 102. From the reading of the machine scales the position of ball 100 can be determined. The machine spindle, with the ball 100 and its associated housing 104 attached, is then moved along one of the machine axes by a distance equal to the length of the ball-bar. The second ball 106 is now seated in the cup 102. The balls 100, 106 may be rotated in their respective cups 102, 108 until the two housings 104, 106 can be connected together by their kinematic joint 114. When proper setting between the cup 108 and ball 106 has been achieved, the adjustment mechanism of the cup is tightened. The ball-bar is now aligned with the machine axis.

To make measurements along the axis, the machine spindle is moved along its axis, carrying the ball 102 and reflector housing by breaking the kinematic joint. The interferometer measures the distance moved.

To prevent sagging of the ball bar when the kinematic joint 114 is broken, the weight of the ball-bar may be counterbalanced, or the magnets used to hold the ball in the cups are made sufficiently powerful to resist the sagging, for example by reinforcing the magnetic force with electromagnets.

To reduce the weight of the ball bar, the light source may be a remote light source connected to the ball bar by a fibre optic cable.

Because the ball-bar can pivot in the cup on the machine spindle, measurement may be made along both the

X and Y axes of the machine by pivoting the ball bar through 90°

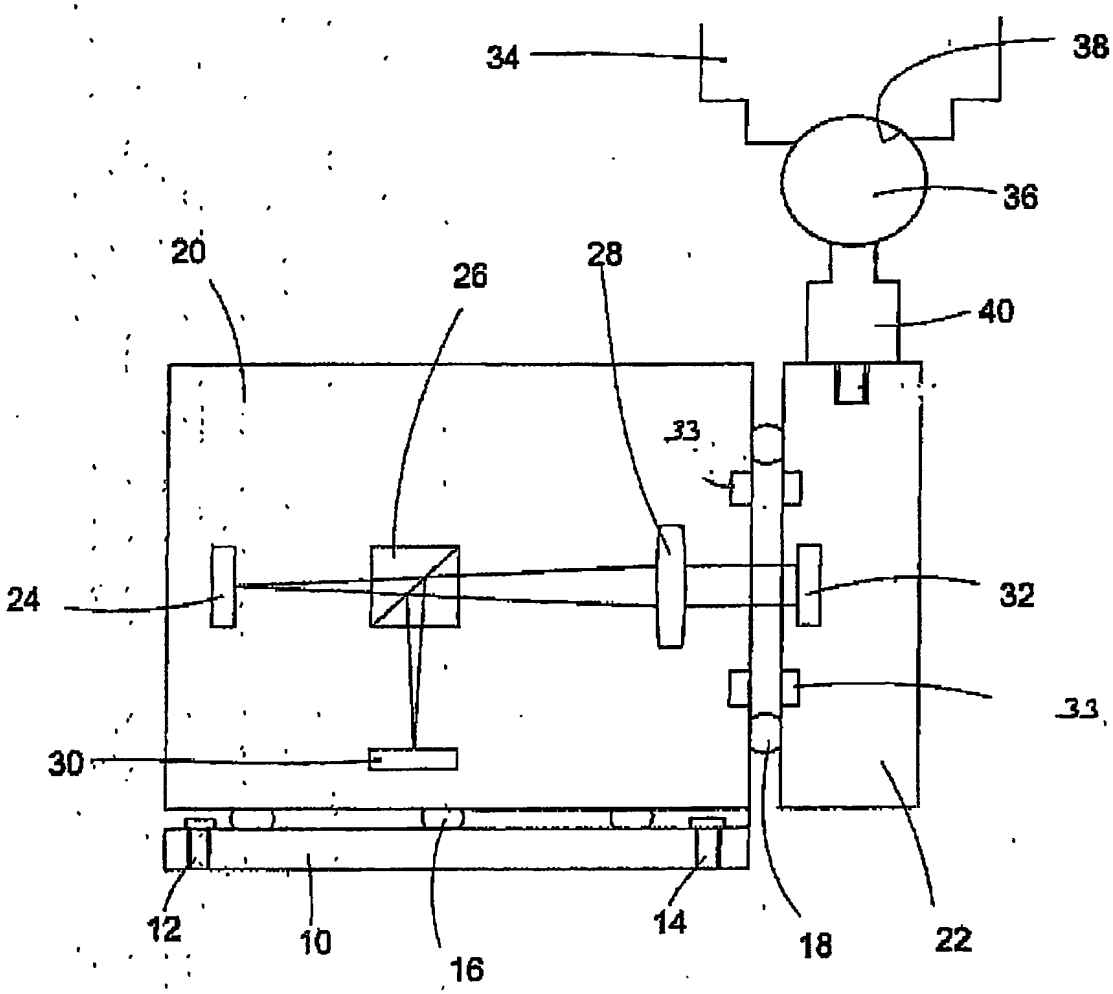
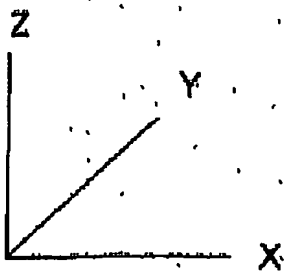


Fig1 (PRIOR ART)



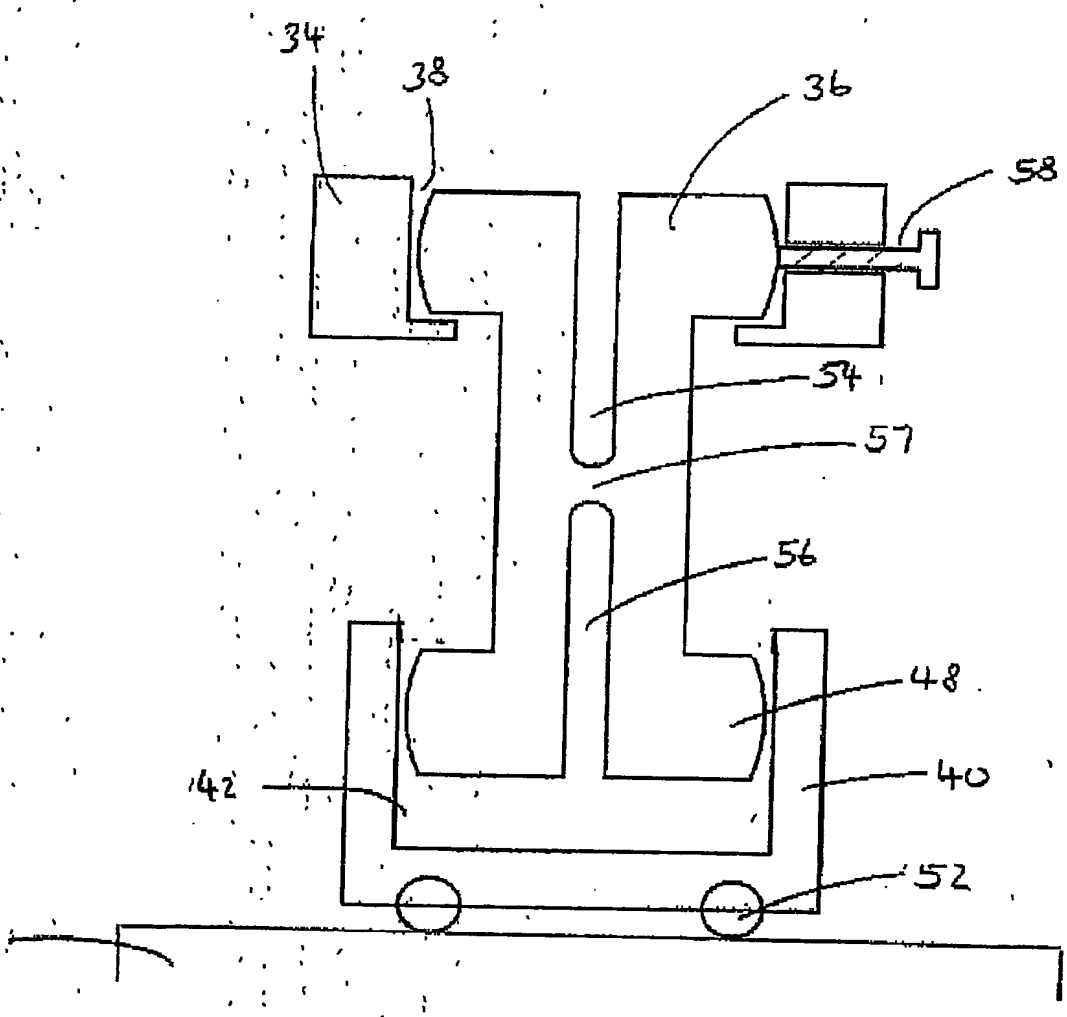


Fig 2

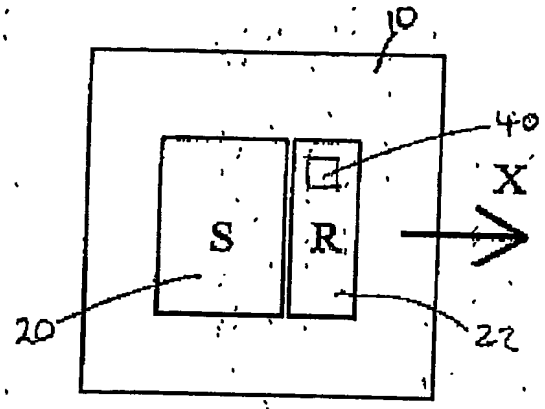


Fig 3A

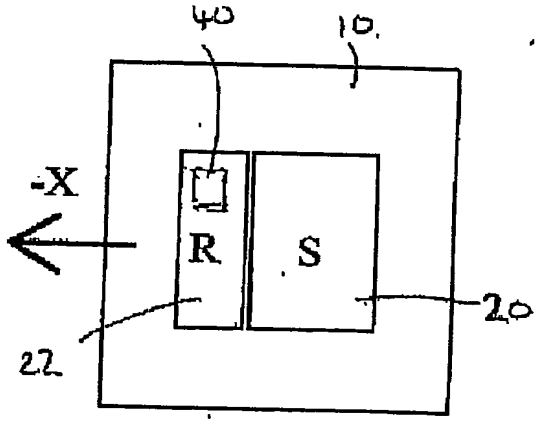


Fig 3C

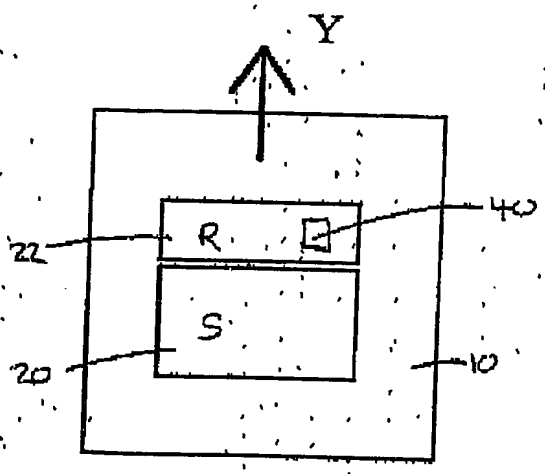


Fig 3B

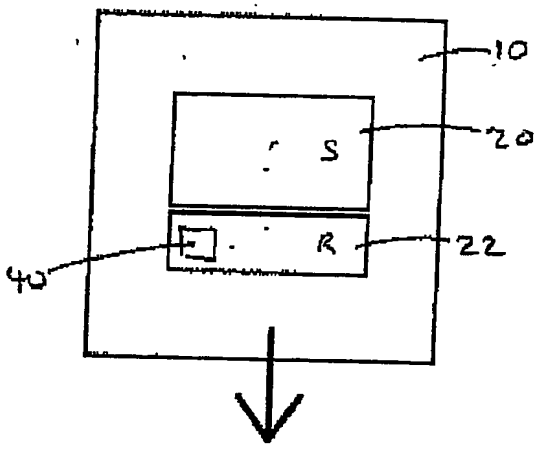
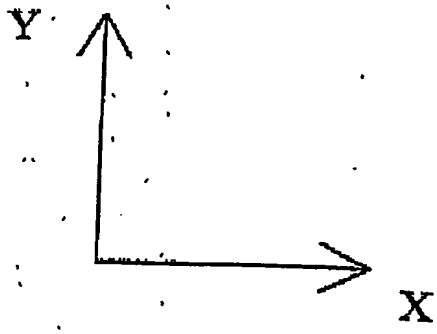


Fig 3D.



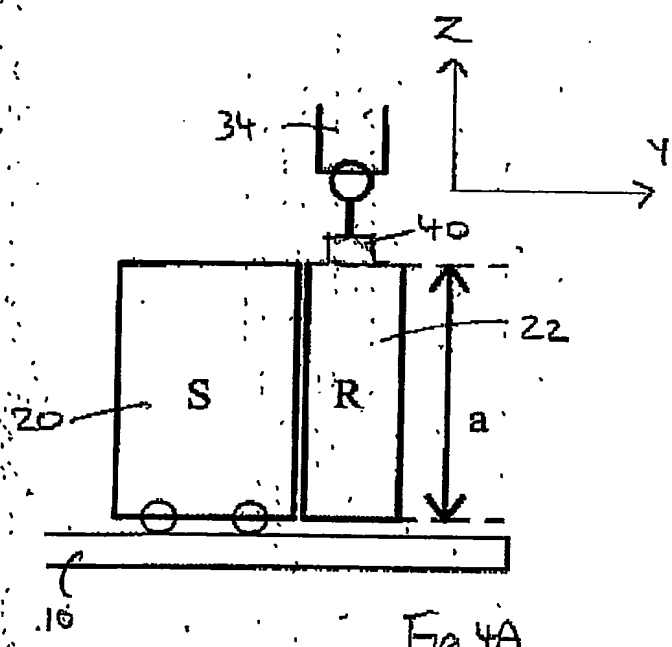


Fig 4A

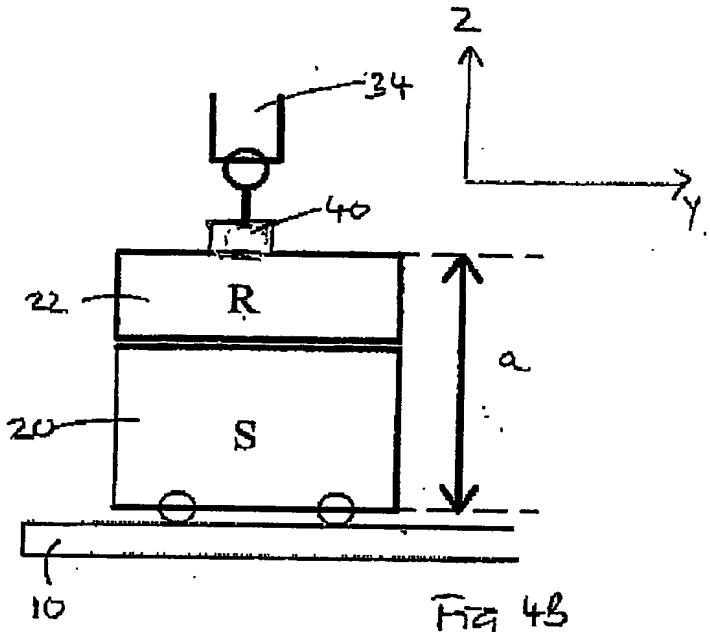
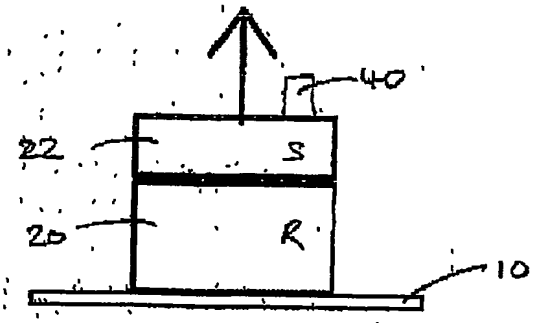


Fig 4B



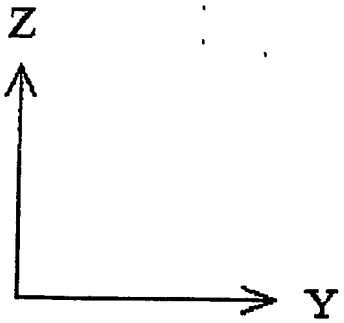


Fig 3E

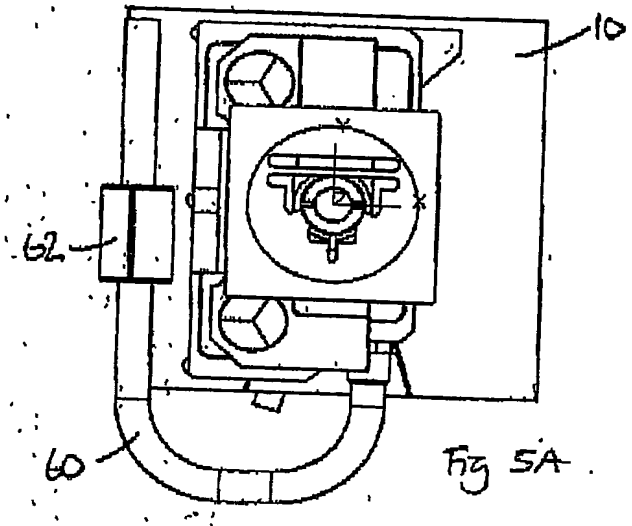


Fig 5A

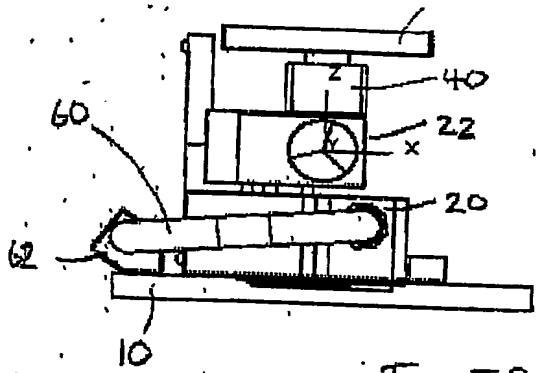


Fig 5B

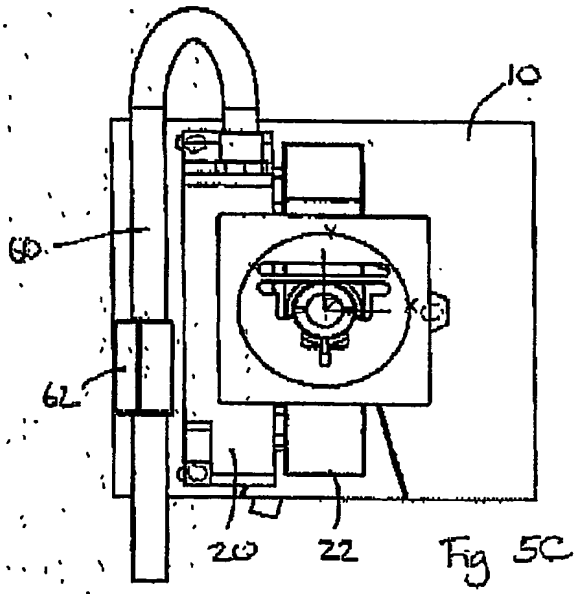
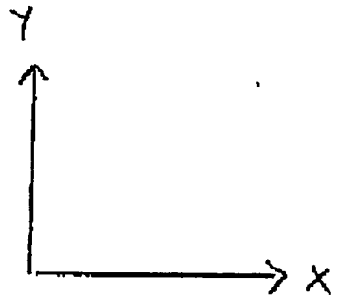


Fig 5C



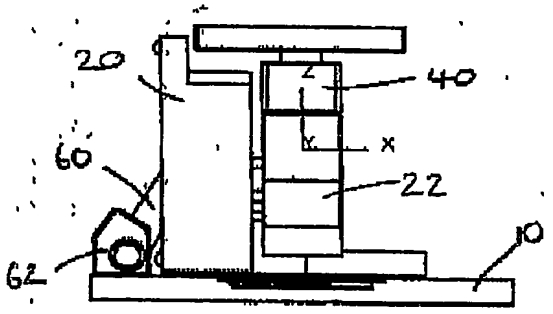
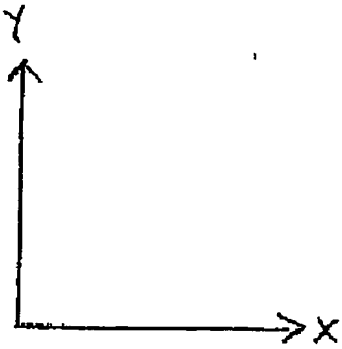


Fig 5D



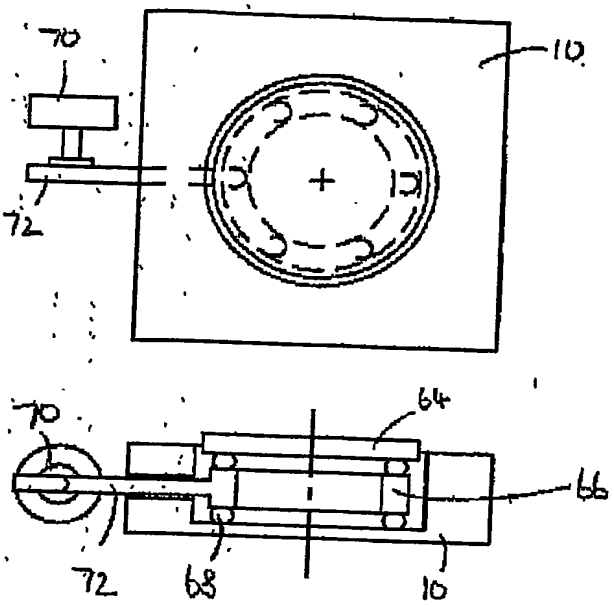


Fig 6A

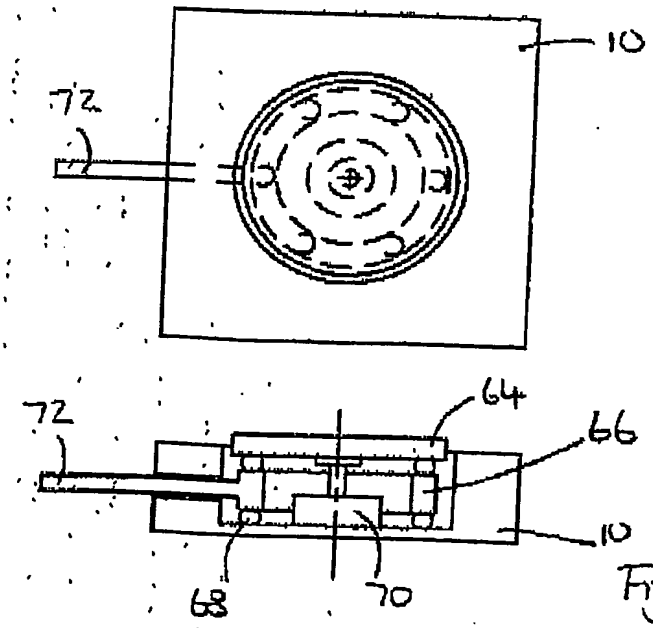


Fig 6B

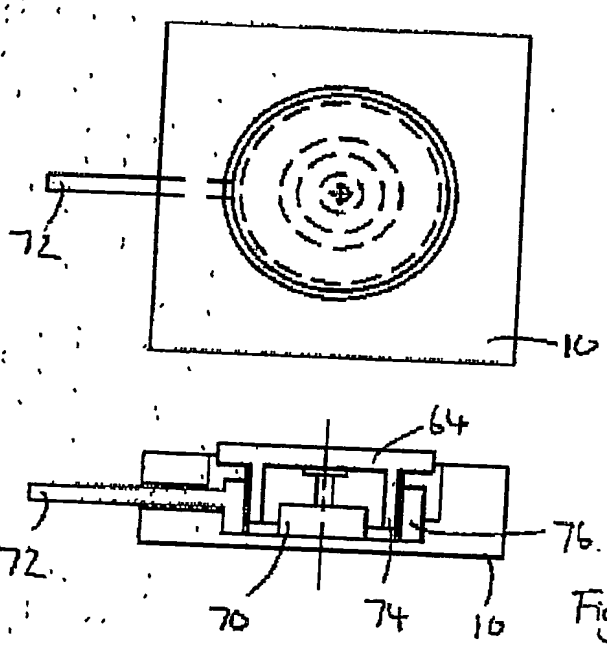


Fig 6D.

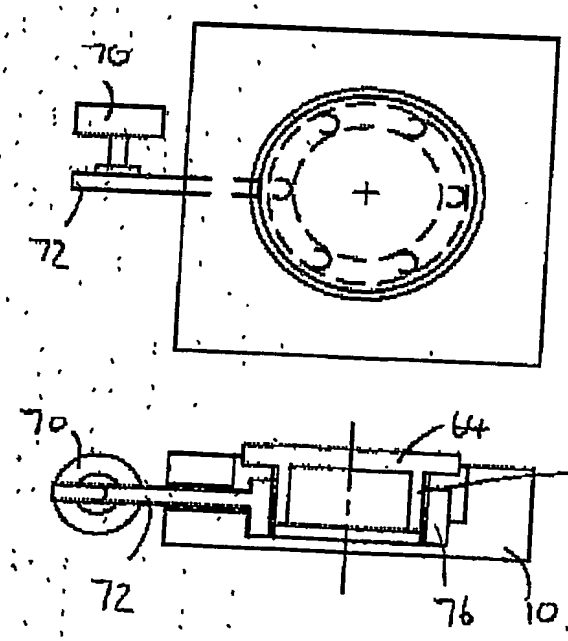


Fig 6C

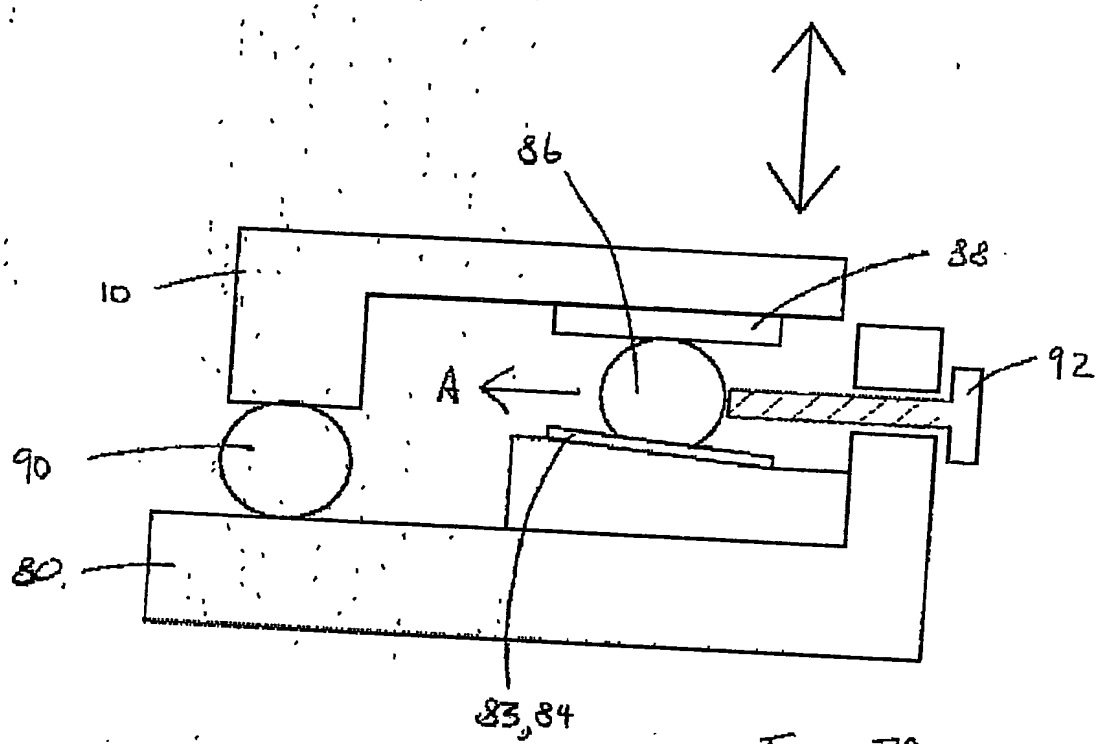


Fig 7A

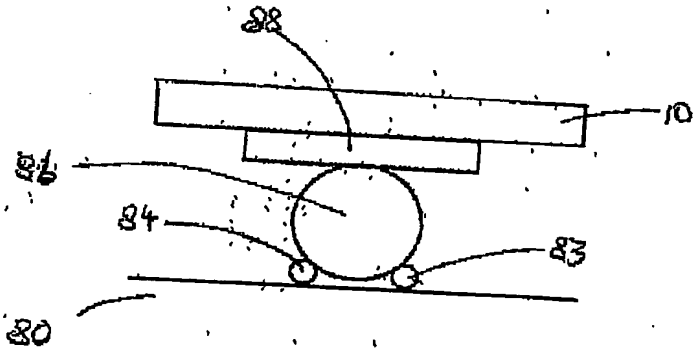


Fig 7B.

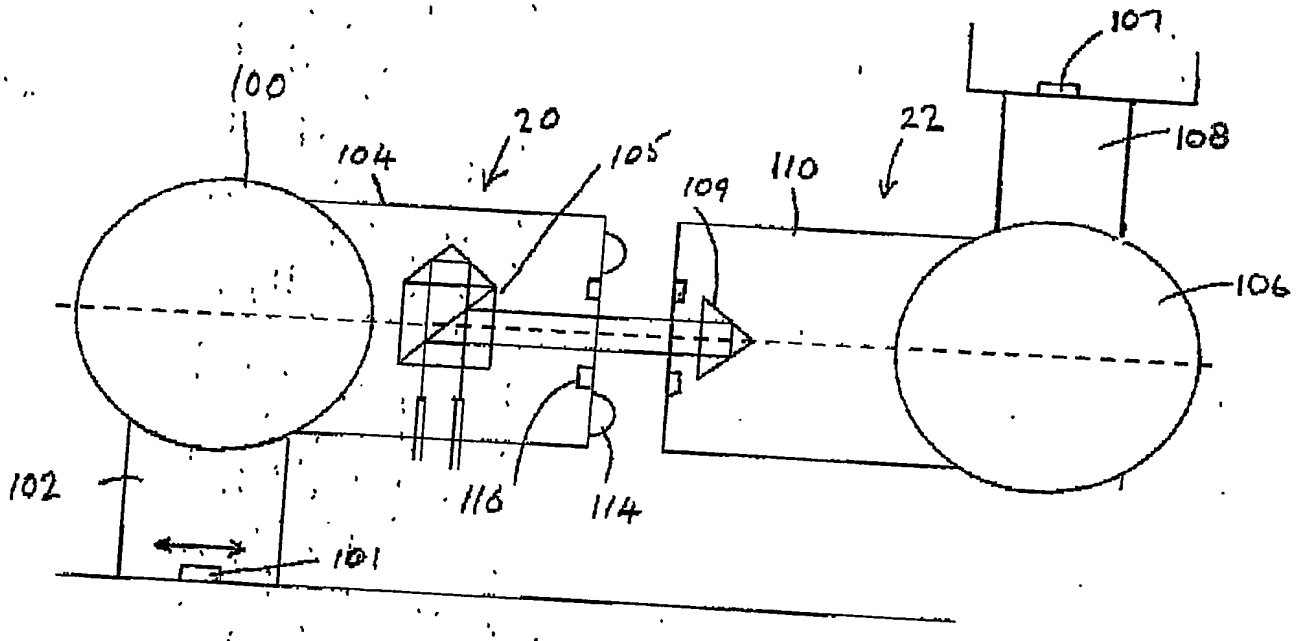
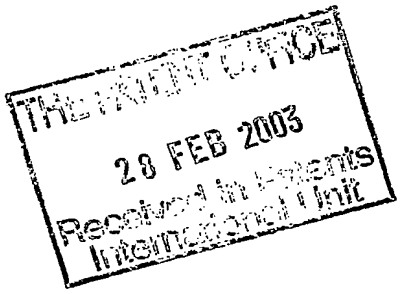


Fig 8.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